"NOVEL MINIATURIZED ANTENNAS AND ARRAYS FOR IMPLANTABLE, INGESTIBLE AND BODY-WORN APPLICATIONS"

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Doctor of Philosophy (PhD)

by

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Farhad Gozasht

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LIST OF ARONYMS USED

Acronym	Expansion
ACMA	Australian Communications and Media Authority
ANSI	American National Standards Institute
A.R	Axial Ratio
AWGN	Additional White Gaussian Noise
BP	Blood Phantom
BS	Base Station
BSN	Body Sensor Node
CAD	Computer Aided Design
CP	Circular Polarization
CP-PIFA	Circular Polarization Planar Inverted-F Antenna
CSRR	Complementary Split Ring Resonator
CPW	Coplanar Waveguide
CSF	Cerebrospinal fluid
DGF	Dyadic Green's Function
DS-PIFA	Dual Slot Planar Inverted-F Antenna
EIRP	Equivalent Isotropically Radiated Power
EM	Electromagnetic
ERP	Effective radiated power
FCC	Federal Communications Commission
FDTD	Finite-difference Time Domain
FHBP	Full Human-Body Phantom
FPCB	Flexible Printed Circuit Board
GI	Gastrointestinal

HWD	Half-Wavelength Dipole
ICP	Intracranial Pressure Monitoring
IEEE	Institute of Electrical and Electronics Engineers
IMD	Implantable Medical Devices
LNA	Low Noise Amplifier
IOP	Intraocular pressure
ISM	Industrial, Scientific and Medical
LS	Least Squares
MBAN	Medical Body Area Network
MBSS-PIFA	Multi Band Single Slot Planar Inverted-F Antenna
MedRadio	Medical Device Radio communications Service
MICS	Medical Implant Communications Service
MLE	Maximum Likelihood Estimation
MRI	Magnetic Resonance Imaging
NI-LMH	Non-Invasive Local Microwave Hyperthermia
NFF	Near-field Focused
PL	Path Loss
PIFA	Planar Inverted-F Antenna
PDF	Probability Density Function
PDMS	Polydimethylsiloxane
PEC	Perfect Electric Conductors
RF	Radio Frequency
RFID	Radio Frequency Identification
RMSE	Root Mean Square Error
RSSI	Received Signal Strength Indicator
Rx	Receiver

SAR	Specific Absorption Rate
SLL	Side lobe level
SS-PIFA	Single Slot Planar Inverted-F Antenna
SRR	Split Ring Resonator
TAP	Transmitter Antenna Position
TBI	Traumatic Brain Injury
Tx	Transmitter
UWB	Ultra Wide Band
VHF	Very High Frequency
VNA	Vector Network Analyzer
WBAN	Wireless Body Area Networks
WCE	Wireless Capsule Endoscopy
WC-PLA	Wideband co-planar loop antenna
WFC-PLA	Wideband folded co-planar loop antenna
WFOLA	Wideband folded oval loop antenna
WMTS	Wireless Medical Telemetry Service
WOLA	Wideband oval loop antenna
WPC-PLA	Wideband printed co-planar loop antenna
WPOLA	Wideband printed oval loop antenna
WPT	Wireless Power Transfer

LIST OF SYMBOLS USED

Symbol	Quantity	Symbol	Quantity
α	Attenuation constant	n	Path loss exponent
β'	Phase constant	Pl	Path Loss
λ	Wavelength	ρ	Density
λ'	Wavelength in lossy mediums	$P_r(d)$	received power
ε	Dielectric constant	P_t	transmitted power
μ	Permeability	σ	Conductivity
G_t	Transmitter antenna gain	G_r	Receiver antenna gain
ϵ_r	Relative permittivity	G_c	Coding gain
S	Scattering parameter	G_d	Fixing deterioration
d	Tx-Rx separating distance	E_b	Energy per bit
$\tan\delta$	Loss tangent	R	Bit rate
l_m	Distance where the mutual coupling reduces significantly between the Tx and Rx antennas	X	Zero mean log-normally distributed random variable
L	Miscellaneous system losses	φ	Phase shift
N_0	Noise power spectral density	VF	Velocity factor
c_b	Blood specific heat	c	Specific heat
T_b	Blood Temperature	T	Temperature
η	Power transmission efficiency	F	Blood flow rate
L_{feed}	Antenna feeding loss	K	Thermal conductivity
C	Distributed capacitance	L	Distributed inductance
Z_0	Characteristic impedance	t	Time
λ_{eff}	Effective Wavelength	$E_{mn}(p)$	Array radiated field
I_0	Feeding current amplitude	F_0	Array focal point

ABTRACT

Implantable medical devices (IMDs) introduced to monitor and transfer physiological information from inside the human body have superb potentials to provide major contributions to disease diagnosis, prevention and therapy. Moreover, minimally invasive biomedical devices helps to reduce the period of long-term hospitalization, so that enhancing the patients' quality of life. Understanding and developing biotelemetry devices, recording/transmitting data from inside the body to the external base station, requires a multi-disciplinary approach. Such a challenging task merges applied solutions, concepts and models from various fields, including biology, electronics, electromagnetism and package/system engineering. Among the device components, the transmitter antenna plays a key role.

Antenna design for biotelemetry applications is extremely challenging due to the effect of the surroundings on the radiator, the essential requirement to miniaturize the antenna structure size, reduced antenna efficiency and the robust effect of multipath losses. More specifically, in this thesis, I design and fabricate several antennas to be integrated in ingestible and implantable devices useful for remote monitoring as well as data biotelemetry. This work also focuses on arrays of body-worn antennas for both wireless endoscope base stations and cancer treatment nearfield microwave systems. Here, my aim is to reduce the physical size of the implantable antennas at specified operating standards frequency bands, while maintaining the antenna electromagnetic performance satisfactory. To achieve this, I introduce and use valuable miniaturization techniques for implantable patch antennas for biotelemetry applications.

Additionally, I design and fabricate compact microwave systems for cancer treatment using electromagnetic (EM) energy. Non-Invasive Local Microwave Hyperthermia (NI-LMH), which is my interest in this thesis, is a heat treatment serves to enhance the effectiveness of chemotherapy or radiation therapy and leads to gain remarkable results. The system may directly apply heat to a fairly small specific area such as tumors to destroy the local cancer cells. To achieve this, the heat effect is developed in the target by the transmission of EM energy, using array of antennas, which is adjusted in frequency, time and strength in order to work together to form a focus in the target. This places high demands on the precision of the system.

In this thesis, I present different planar antenna array for non-invasive microwave hyperthermia applications. The new Near Field Focused (NFF) arrays operates at ISM 2.45 GHz band and consists of 5 to 25 miniaturized dual slot PIFAs, depends on the array geometry arrangement. The arrays immersed inside a coupling bolus occupies a very small volume of space results in an easy fitting to contoured patient anatomy. These arrays, which are low profile and lightweight, have both superficial and deep focusing properties. The novel NFF body worn arrays are capable to focus on a single target with a high level of accuracy to concentrate the EM energy only on the target. I employ optimized dual slot PIFAs as array elements to reduce the size of the focusing area so that destroying very small tumors and avoid heating up the surrounding healthy cells.

I have also introduced size reduced NFF array to simplify the feeding network of the applicator and reduce the system cost, this array configuration satisfies system requirements and can focus on small targets precisely while keep the penetration depth high enough to heat up the deep seated targets.

In addition, the performance of both fabricated narrowband and wideband single antennas and array of antennas verified using experimental tissue mimicking phantoms. To validate the dielectric properties of experimental phantoms, over different frequency bands, dielectric probe kit employed, furthermore, optical fibre thermometers employed to confirm specific absorption rate (SAR) values for implanted radiators.

Index Terms – Antennas in lossy matter, Electrically small antennas, PIFA miniaturization method, SAR, Biocompatible insulation, Implantable and ingestible antennas, Rx and Tx antenna for wireless capsule endoscopy, Body centric wireless communications, compact antenna for head implants, Body Sensor Node (BSN), standards biotelemetry bands, array antenna for non-invasive local hyperthermia, Medical Device Radio communications Service (MedRadio), Medical Implanted Communication System (MICS).